Climate Factors and Crop Growth: Physiology and Mechanistic Modelling

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Food production on long-term space missions

Use knowledge from greenhouse horticulture and production in climate rooms (plant factories)

- Plant development versus plant growth
- Climatic factors (focus on temperature and light)
- Mechanistic crop models

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Growth versus development

- Growth: increase in size (length, area, mass)
  - Main influencing factors: light and CO_2
- Development: phase transitions/ formation of new organs

The systematic movement along the genetically programmed sequence of events during the life cycle

  - Main influencing factor: temperature

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Higher temperature -> faster development

Temperature (°C)	Fruit dry weight (g)	Fruit growth period (days)
17	4.8	74
19	4.3	63
21	3.2	56
23	2.7	50

- At higher temperature harvest starts earlier and fruits are less heavy

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Source: A.N.M. de Koning

The role of light in plant growth

- Light intensity (amount): Energy for photosynthesis = basic process for plant growth
- Daylength: Flowering (sometimes also growth, tomato minimum night length required)
- Light color (spectrum): Plant shape, bud break, abortion, developmental processes
- Light direction/diffuse: Plant shape; light distribution in a crop → photosynthesis
- Heat

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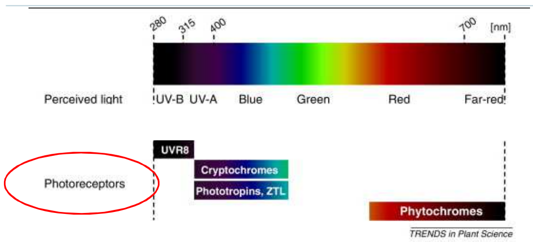
How do plants perceive light ?



Phytochromes: R/FR ratio; elongation, flowering
Cryptochromes: day length
Phototropins: movement to light, stomatal opening

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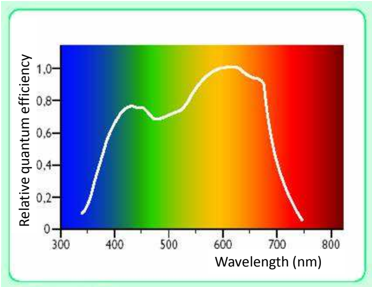
Heide and Ulm, 2012

Light spectrum (color): Plant sensitivity for photosynthesis



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Effect of light spectrum on growth and morphology

100%Red 88Red/12Blue 100%Blue White Extra Farred

LED light; climate room; 150 µmol m^{-2} s^{-1}; genotype RF-206

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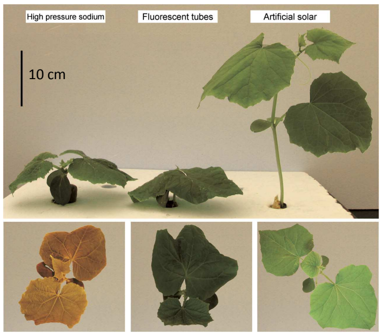
Ouzounis et al., unpublished

Spectral effects on morphology determine effect on biomass



Leaf absorptance growth-light (%)

HPS	FT	AS
86	87	85

Net assimilation at growth irradiance

HPS	FT	AS
4.9[b]	4.9[b]	4.5[a]

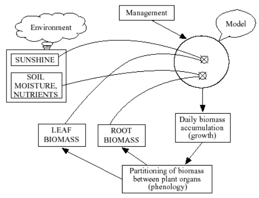
Total plant dry weight

HPS	FT	AS
611[b]	440[a]	1001[c]

Hogewoning et al., 2010

Crop models

- Powerful tools for
  - Testing hypotheses
  - Scenario analysis
  - Integrating knowledge



- Applications
  - Decision support systems
  - Monitoring
  - Greenhouse climate control
  - Prediction and planning of production

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Many different complexity levels of models

- Regressions models (direct relationship between input and output)
- Mechanistic models (at least one level underlying output),

from rather simple

Light Use Efficiency model (LUE, Harvest index)

to more complex

Leaf photosynthesis (FvCB biochemical model), respiration, dynamic partitioning based on sink strengths etc.

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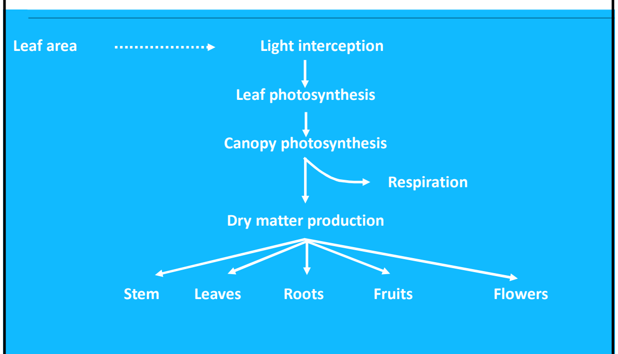
General scheme of a crop growth model



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Dry matter production : a simple LUE model

$dW/dt = LUE\,(1-e^{-k\,LAI})\,I$

dW/dt = growth rate (g DM m^{-2} d^{-1})

LUE = light use efficiency (g DM MJ^{-1} PAR)

k = extinction coefficient

LAI = Leaf area index

I = Photosynthetic Active Radiation (PAR) incident on crop (MJ m^{-2} d^{-1})

Assumes constant LUE !

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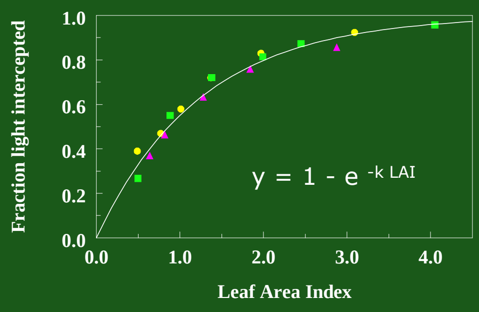
Influence of Leaf Area Index (LAI) on the fraction of light intercepted by a tomato crop (k = extinction coefficient = 0.8)



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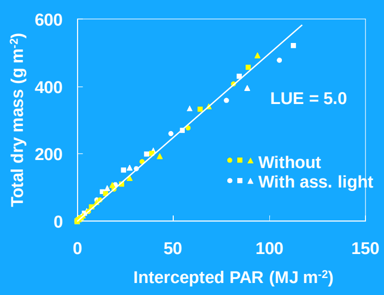
Light use efficiency (LUE, g MJ^{-1}) in winter: 3 plant densities with or without assimilation light for cut chrysanthemum



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Example of calculation of CO_2 uptake and O_2 production

LUE = 5 g DM MJ^{-1} light ≈ 1.0 g DM mol^{-1} light (HPS lamp light)

Lettuce canopy; 20 h 500 μmol m^{-2} s^{-1} = 36 mol m^{-2} d^{-1}

Assume 90% light interception

Hence growth rate: 36 x0.9 x 1.0 = 32.4 g DM m^{-2} d^{-1}

Dry matter contains 45% C, hence 14.6 g C (53.5 g CO_2 uptake)

Same moles O_2 emission: 53.5/44 = 1.22 mole = 39 g O_2

Daily O_2 requirement for Human Life Support for Long Duration Space Missions (NASA SPP 30262 document): 0.83 kg;

hence 830/39 = 21 m^2 lettuce canopy needed for O_2 requirement 1 person !

Note: this all depends strongly on the exact conditions !

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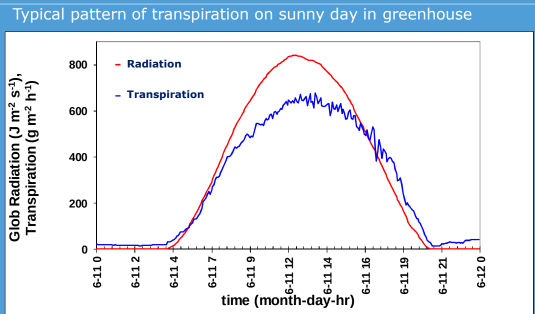
Crop water demand

Typical pattern of transpiration on sunny day in greenhouse



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Nutrient demand ≠ Water demand

- Water demand mainly determined by transpiration rate
- Nutrient demand mainly determined by growth rate and required organ concentrations (depend on organ developmental stage)

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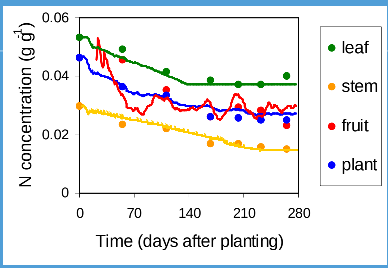
Nutriënt concentration in plant organs depends on crop stage (if no shortage).



Growth rate and N-concentration in the plant determine total N-requirement

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Assimilate partitioning
(edible versus non-edible parts)

- Fixed harvest index (e.g. 0.5 for wheat)
- Predetermined ratios
- Regulation based on organ sink strength

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Biomass partitioning
- sink regulation - relative sink strength -

Fraction of Dry Matter partitioned to an organ is a function of its relative sink strength.

- $f_i = S_i / \Sigma S$

f_i = fraction of dry matter partitioned to organ i

S_i = sink strength of organ i

ΣS = total sink strength of all organs

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Removal of young leaves: A simulation study

- More sugars will be partitioned to the fruits (as ratio fruits: leaves is higher)

But:

- Less leaf area (LAI) and therefore perhaps less growth and yield

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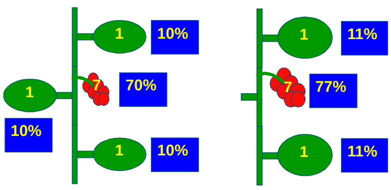
Removal of young leaves

Fruits will get :

$$\frac{7}{(7+1+1+1)} = 0.7 \qquad \frac{7}{(7+1+1)} = 0.77$$



Yellow numbers inside leaves and truss = 'sink strength'

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Simulated cumulative fruit and total dry weight, fraction partitioned to the fruits and average LAI
Treatment = removal of young leaves

Treatment	DW_{fruit} (kg m^{-2})	DW_{total} (kg m^{-2})	F_{fruits}	LAI_{av} (m^2 m^{-2})
Control	2.93	4.26	0.69	2.48
1 out of 6	2.90	4.08	0.71	2.06
1 out of 3	2.79	3.79	0.74	1.63

- Removal of old leaves according to developmental stage of the corresponding truss
- Tomato crop grown from 1 December till 26 November

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Simulated cumulative fruit and total dry weight, fraction partitioned to the fruits and average LAI

Treatment = removal of young leaves

Treatment	DW_{fruit} (kg m^{-2})	DW_{total} (kg m^{-2})	F_{fruits}	LAI_{av} (m^2 m^{-2})
Control	2.92	4.25	0.69	2.41
1 out of 6	3.01	4.24	0.71	2.38
1 out of 3	3.11	4.22	0.74	2.33

- Removal of leaves from oldest vegetative unit every time LAI>3
- Tomato crop grown from 1 December till 26 November

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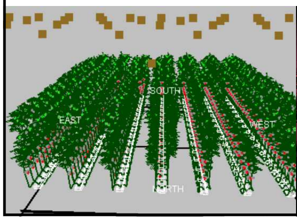
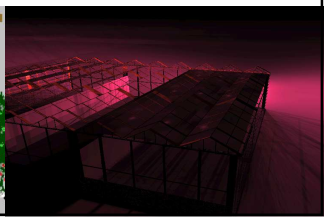
Pruning of young leaves improves yield (by about 6%) if LAI is kept sufficiently high

FSPM: Functional Structural Plant Models

- •Many process-based models for greenhouse crops
- •No consideration of 3D canopy structure nor 3D light distribution
- •FSPM combines function and structure





Ideotype plant architecture tomato

- open canopy structure
  (longer internodes, longer petioles)
  → +10% crop photosynthesis

Dense structure

Open structure

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Sarlikioti, de Visser, Marcelis, 2011, Ann. Bot.

Conclusions

- Plant development mainly driven by temperature
- Plant morphology and therefore growth strongly influenced by light spectrum
- Mechanistic models important tools for scenario analysis and integrating knowledge

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Thank you for your attention

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